The Pierre Auger Observatory: studying atmospheric electricity with cosmic-ray detectors

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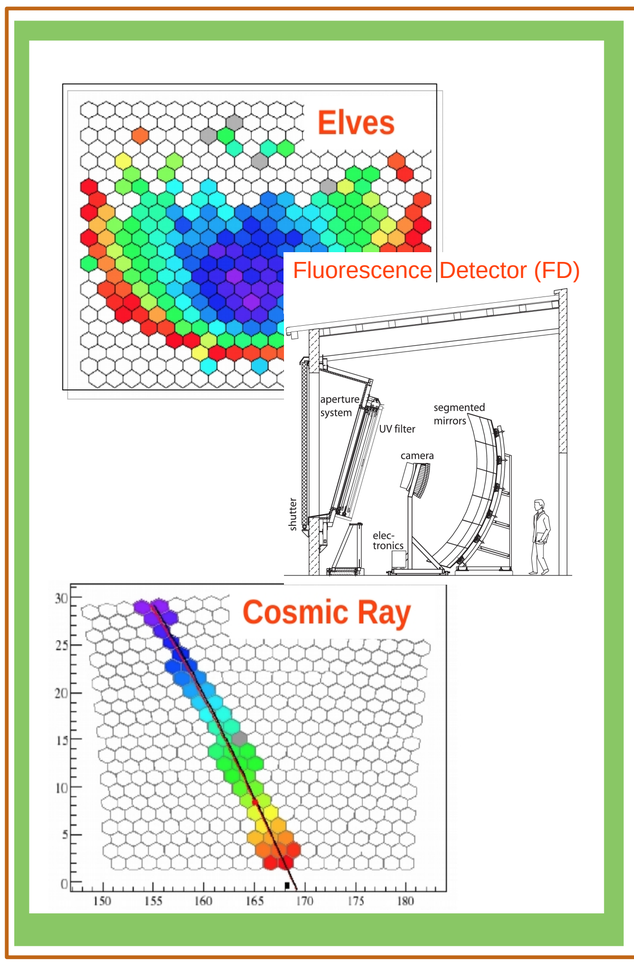
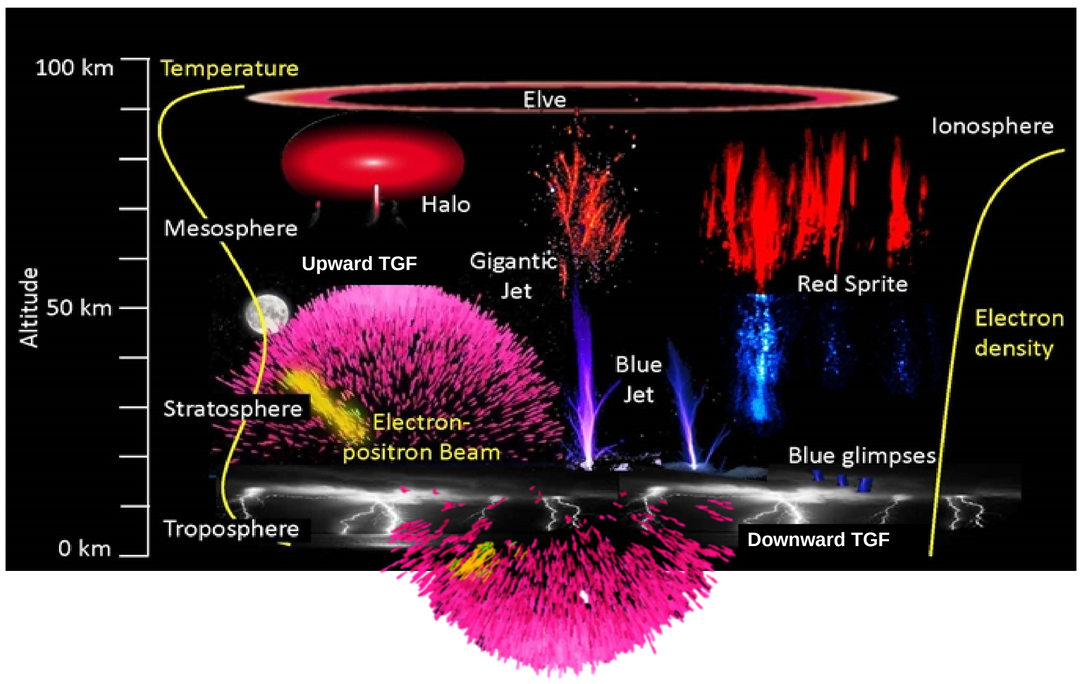
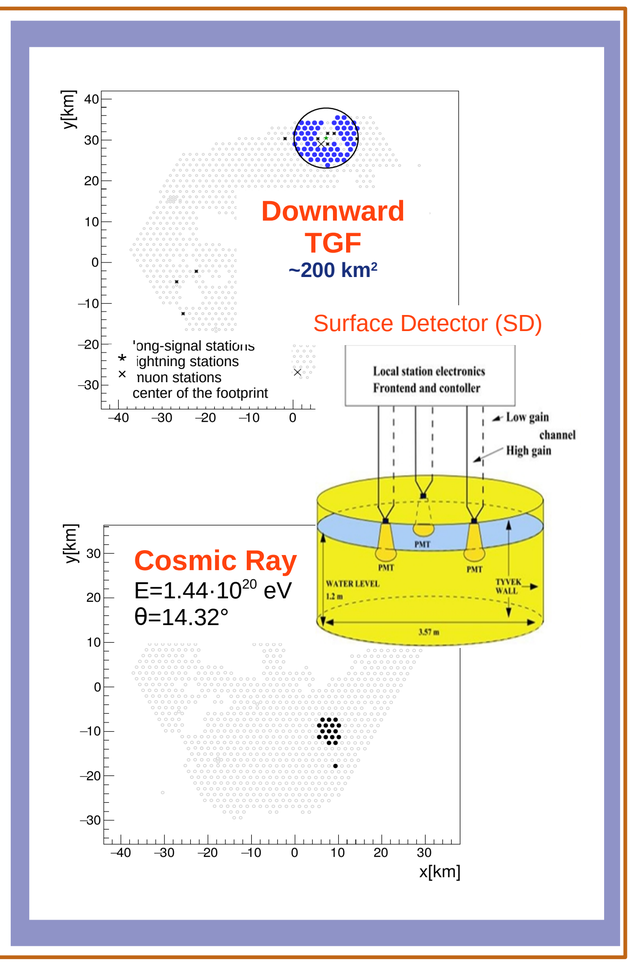
PIERRE AUGER OBSERVATORY





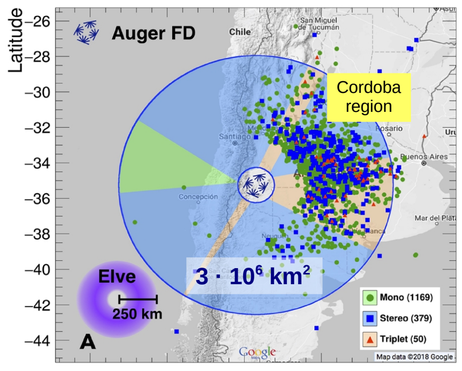


Thunderstorms are the most energetic natural particle accelerators on Earth [1]. Very bright events are produced in coincidence with lightning and the Pierre Auger Observatory [2], the largest cosmic-ray detector in the world, proved to be a unique instrument to study these phenomena.

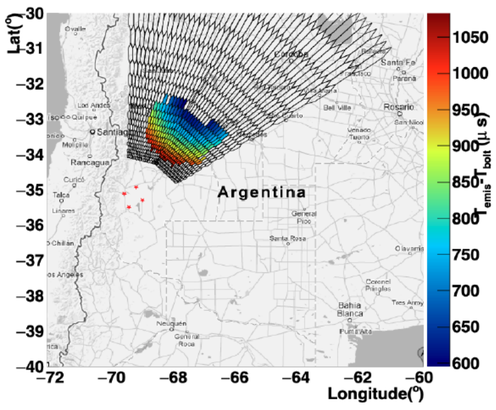
ELVES: transient luminous events occuring at the base of the ionosphere triggered by lightning in the troposhere [3].

TGFs: millisecond pulses of gamma rays usually observed by spacecrafts [5].

Emission of Light and Very Low Frequency perturbations due to Electromagnetic Pulse Sources (ELVES)

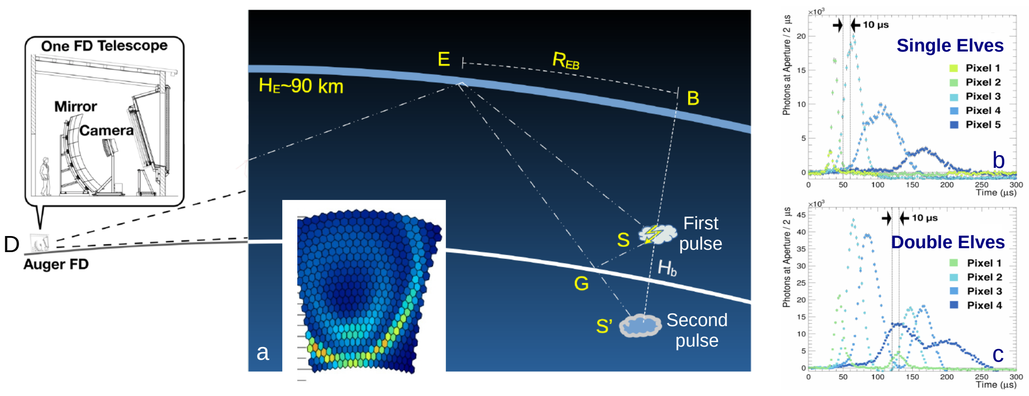


ELVES appears as rapidly expanding rings.
More than 95% of the observed ELVES are 250-1000 km away, where the FoV of a telescope crosses the ionosphere and direct light from lightning is blocked by the limb of the Earth.

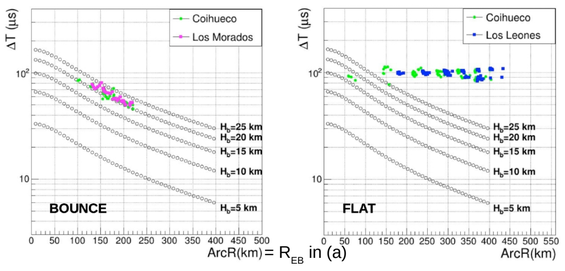


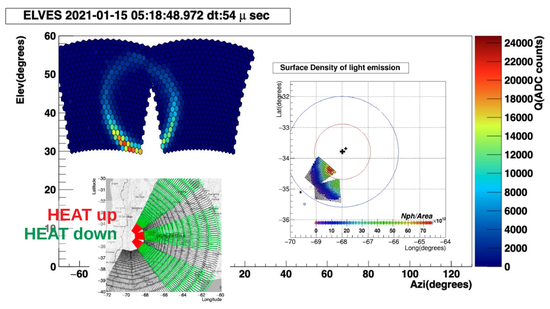
An ELVES projected at the emission layer at the base of the ionosphere, after correcting for the transit time from the emission layer to the FD. Colors represent the time evolution.

Thanks to the Auger FD time resolution, the temporal structure in the light emission of ELVES can be observed very fine and data can be sorted in two categories studying the photon trace: **single-peaked (b) and multipeaked ELVES (c)** [6].



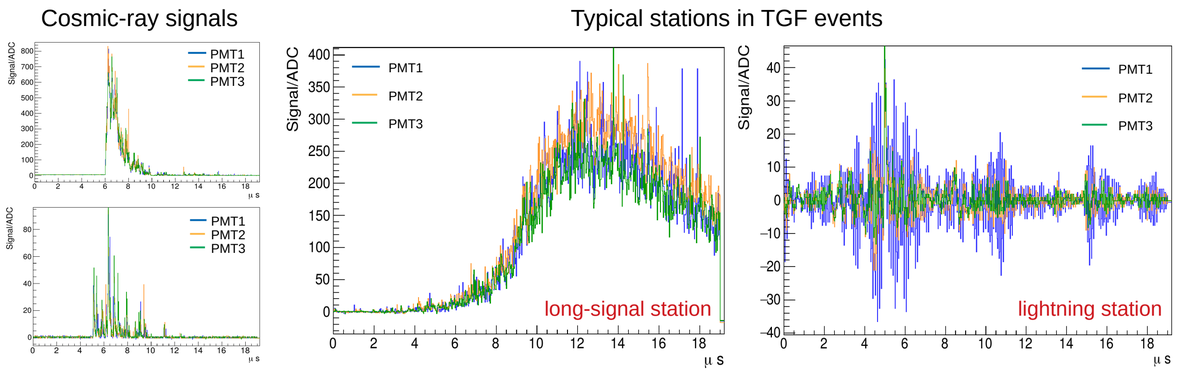
ELVES are produced by the ElectroMagnetic Pulse (EMP) emitted during the lightning return stroke or in initial breakdown stages of the discharge. The production mechanism for two or more consecutive ELVES rings in less than 1 ms is not clear yet, but ground reflection is the most common explanation for double ELVES [4]. In picture (a), the geometric model for the calculation of the time gap between the first (light path: SED) and the second pulse (light path: S'ED) observed in a given pixel is shown.
By studying the time gap between pulses in each pixel, we found that a large fraction of double ELVES cannot be explained as ground reflection (**bounce**) of the EMP (d). The study of the ratio between the intensity of the two pulses is showing a variety of patterns, suggesting that multiple ELVES are due to several causes.
A new trigger on the HEAT telescopes allows us to observe closer lightning and better study double ELVES from low clouds that cannot be resolved in the other telescopes [7].





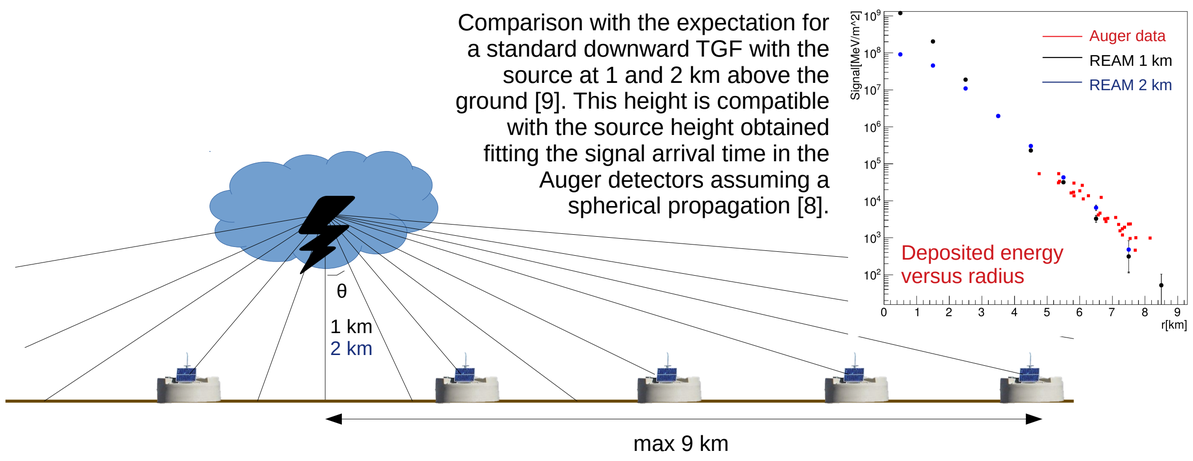
The comparison of ELVES light curves with the signals from ENTLN antennas [12], deployed in Argentina in 2018, will allow us to correlate the feature of double ELVES with the polarity of intracloud lightning and return strokes.

Terrestrial Gamma-ray Flashes (TGFs)

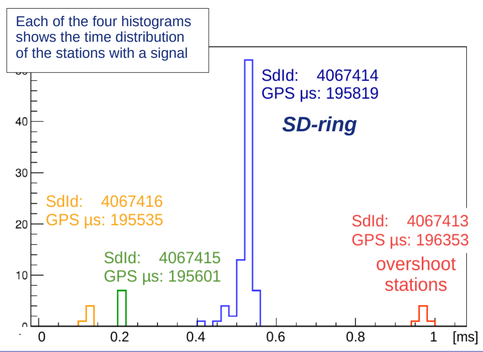


The presence of **lightning stations**, characterized by high-frequency noise, suggested that the observed "peculiar" events, so different from cosmic-ray events, happened during thunderstorms. By finding a correlation between our events and the lightning strikes collected by the World Wide Lightning Location Network [11], this hypothesis was verified. It was supported also by the measurements of the atmospheric monitoring instruments available at the Pierre Auger Observatory.
The Auger Water-Cherenkov Detectors have a **high efficiency for gamma-ray detection**. Auger is observing **the brightest events** (~ 10^4 MeV/m²) at the ground connected with lightning activity, most likely TGFs [10].
It is known that **TGFs** are produced by the Relativistic Runaway Electron Avalanche (**RREA**) process. When a "seed electron", travelling in a thundercloud region that contains a strong electric field, gain more energy than that lost predominately due to ionization, we say that it "runaways" and activates the electron avalanche. It is not yet clear **what provides the "seed electron"**. The two main models, "Lightning Leader" and "Relativistic Feedback" can be constrained studying the **rising edge of the long-lasting signals**.

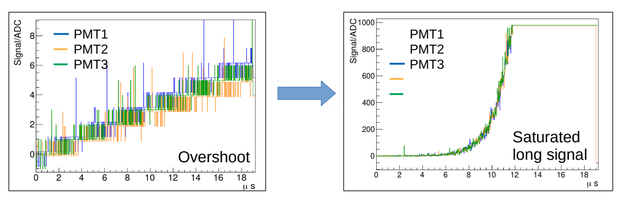
Comparison with the expectation for a standard downward TGF with the source at 1 and 2 km above the ground [9]. This height is compatible with the source height obtained fitting the signal arrival time in the Auger detectors assuming a spherical propagation [8].



The rate of TGF events is less than 2 events/year (about 30 events/year are expected) and most of them present a lack of signal at the center of the footprint (plot in the top box - SD-ring). It was verified that this signature has not a physics origin [10], but is due to the Auger trigger and acquisition chain optimized for cosmic-ray events. An algorithm to tag long-lasting signals has been recently developed using differences of integrals performed over predefined parts of the trace and it is now installed in the whole array. **We expect to increase the TGF rate modifying the CDAS (Central Data Acquisition System) read-out logic to give priority to events which contain long-lasting signals**.



The stations involved in the two events preceding the SD-ring are all in the footprint of the SD-ring and complete it. Also the stations of the following events are in the center of the footprint. The signal of these stations is due to an overshoot of the electronic that may trigger the stations and that is an hint of large saturated signals.



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[12] https://www.earthnetworks.com.